New Frontiers in The Solar System.

An Integrated Exploration Strategy

Solar System Exploration Survey

Space Studies Board

National Research Council

6 August, 2002

The Charge to the Survey:

- **Define a "big picture"** of solar system exploration - what it is, how it fits into other scientific endeavors, and why it is a compelling goal today.
- **Conduct a broad survey** of the current state of knowledge about our solar system today.
- **Identify the top-level scientific questions** that should provide the focus for solar system exploration today; these will be the key scientific inputs to the roadmapping activity to follow.
- **Draft a prioritized list** of the most promising avenues for flight investigations and supporting ground-based activities.

Ground Rules

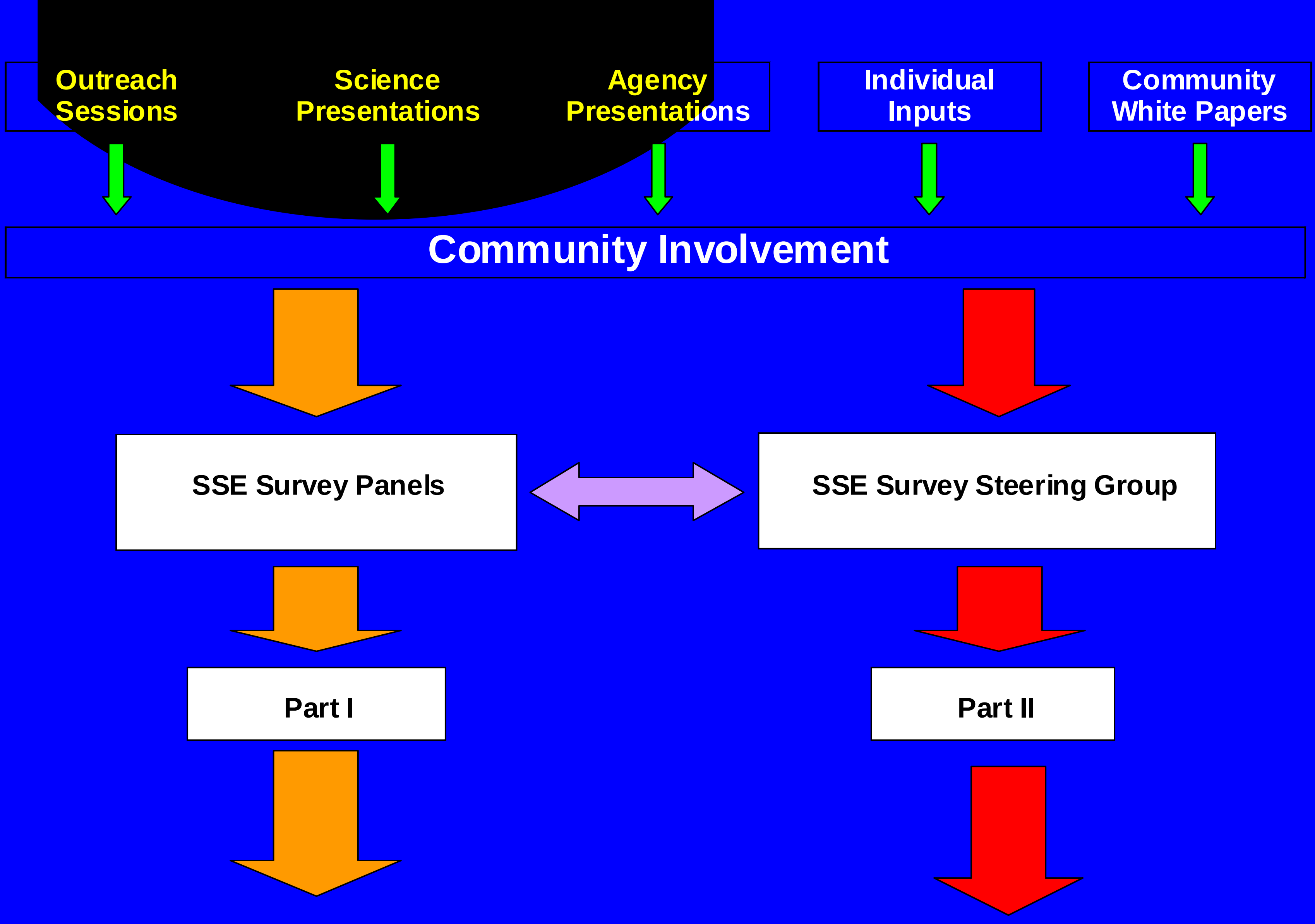
- Model effort on NRC Astronomy Decadal Surveys
- Provide mission priorities within “cost bins”
- Prioritize the Mars Program and the Solar System Program independently
- Do not prioritize individual missions in the Discovery and Mars Scout programs.

Members of Survey

- **Michael Belton** (Chair) – Belton Space Exploration Initiatives, LLC
- **Carolyn Porco** (Vice Chair) – Southwest Research Institute
- **David H Smith** (Study Director) - NRC

- **Michael A'Hearn** – Univ. Maryland
- **Joseph Burns** - Cornell University
- **Ronald Greeley** – Arizona State U.
- **James Head III** – Brown Univ.
- **Wesley Huntress** – Carnegie Inst.
- **Andrew Ingersoll** – Cal. Inst. Tech
- **David Jewitt** – Univ. Hawaii
- **John Mustard** – Brown Univ.
- **Andrew Nagy** - Univ. Michigan
- **Dimitri Papanatassiou** - JPL
- **Robert Pappalardo** – Univ. Colorado
- **Mitchell Sogin** - Marine Bio. Lab.
- **A. Thomas Young** – Retired

Mars panel (COMPLEX) – **John Wood**
Inner Planets Panel – **Carle Pieters**
Giant Planets Panel – **Reta Beebe**
Primitive Bodies Panel – **Dale Cruikshank**
Large Satellites Panel – **Alfred McEwen**
Ad hoc Astrobiology Panel (COEL)
- **Jonathan Lunine/John Baross**



New Frontiers in Solar System Exploration

New Frontiers in the Solar System
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Community interactions

- Town hall meetings
- Web page bulletin board discussions: DPS, AGU, GSA
  > 300 scientists
- White Papers from community .panels These reports are now published as a book (Mark Sykes [Ed.], The Future of Solar System Exploration 2003-2013, ASP Conference Series Vol. 272.)
- Polls by DPS and Planetary Society

Ad hoc Community Panels

- Planetary Atmospheres
- Education and Public Outreach
- The Future of Io Exploration
- Dust Astronomy
- Near-Earth Asteroid Sample Return
- Sub-orbital Program
- Titan
- Mercury
- Mars
- Planetary Rings
- Solar System Astrometry
- Europa Exploration
- Neptune System Exploration
- The Kuiper Belt
- Radio Science and the DSN
- Terrestrial Analogs to Mars
- Extraterrestrial Mineralogy
- Venus
- Instrument Technology Development
- Comets
- Lunar Exploration, Manned and Unmanned
- Near-Earth Objects – Discovery, Tracking, Characterization
- The Next Giant Leap- Human Exploration and Utilization of NEOs

The Selection and Prioritization Process:

Motivational Goals

▼

Scientific Goals

▼

Scientific Themes and 12 Key Scientific Questions

▼

Mission Selection

▼

Mission Prioritization

Why is Solar System Exploration a Compelling Activity Today:

- **Solar system exploration is that grand human endeavor** which reaches out through interplanetary space to discover the nature and origins of the system of planets in which we live, and to discover whether life exist beyond Earth.

- **It places *within our grasp* answers to questions of profound** human interest:

    - ***Are we alone?***
    - ***Where did we come from?***
    - ***What is our destiny?***

Relationship Between Motivational Questions and Scientific goals

- ***Are we alone?***
  - **Determine how life developed in the solar system, where it may have existed, whether extant life forms exist….**
- ***Where did we come from?***
  - **Learn how the Sun's retinue of planets originated and evolved.**
  - **Discover how the basic laws of physics and chemistry, acting over aeons, lead to diverse phenomena…**
- ***What is our destiny?***
  - **Explore the terrestrial space environment to discover what potential hazards…**
  - **Understand how physical and chemical processes determine the main characteristics of the planets…**

Scientific Themes for 2003 – 2013:

- **The first billion years of solar system history**
- **Volatiles and organics: The stuff of life**
- **The origin and evolution of habitable worlds**
- **Processes: How planetary systems work**

Themes → Key Scientific Questions → Missions

The first billion years of solar system history - - -

- **What processes marked the initial stages of planet formation?**
- **Over what period did the gas giants form, and how did the birth of the ice giants (Uranus, Neptune) differ from that of Jupiter and its gas-giant sibling, Saturn?**
- **How did the impactor flux decay during the solar system's youth, and in what ways(s) did this decline influence the timing of life's emergence on Earth?**

Themes → Key Scientific Questions → Missions

Volatiles and Organics: The stuff of life- - -

- **What is the history of volatile compounds, especially water, across our solar system?**
- **What is the nature of organic material in our solar system and how has this matter evolved?**
- **What global mechanisms affect the evolution of volatiles on planetary bodies?**

Themes → Key Scientific Questions → Missions

The origin and evolution of habitable worlds- - -

- **What planetary processes are responsible for generating and sustaining habitable worlds, and where are the habitable zones in our Solar System?**
- **Does (or did) life exist beyond the Earth?**
- **Why have the terrestrial planets differed so dramatically in their evolutions?**
- **What hazards do solar system objects present to Earth's biosphere?**

Themes → Key Scientific Questions → Missions

Processes: How planetary systems work- - -

- **How do the processes that shape the contemporary character of planetary bodies operate and interact?**
- **What does our solar system tell us about the development and evolution of extrasolar planetary systems, and vice versa?**

Mission Priorities in Solar System Exploration for the Next Decade…

- **New Solar System Flight Missions (non-Mars)**
- **Mars Flight Missions (beyond 2005)**

  Three Cost Classes:

  - Small (<\$325M) – Discovery, Scout, and mission extensions
  - Medium (<\$650M) – New Frontiers
  - Large (>\$650M) – Flagship

- **New Ground Based Activities**

Criteria Used for Judging Priorities:

- **Scientific Merit:**
  - Might a reigning paradigm be overturned?
  - Will knowledge reset research directions?
  - Will measurements substantially broaden database?
- **Opportunity**
- **Technological readiness**

Solar System Mission Priorities:

- *Small Class (<$325M)*

1. Discovery missions at one launch every 18 months
2. Cassini Extended mission (CASx)

- *Medium Class (<$650M) – New Frontiers*

1. Kuiper Belt/Pluto (KBP)
2. South Pole Aitken Basin Sample Return (SPA-SR)
3. Jupiter Polar Orbiter with Probes (JPOP)
4. Venus In-situ Explorer (VISE)
5. Comet Surface Sample Return (CSSR)

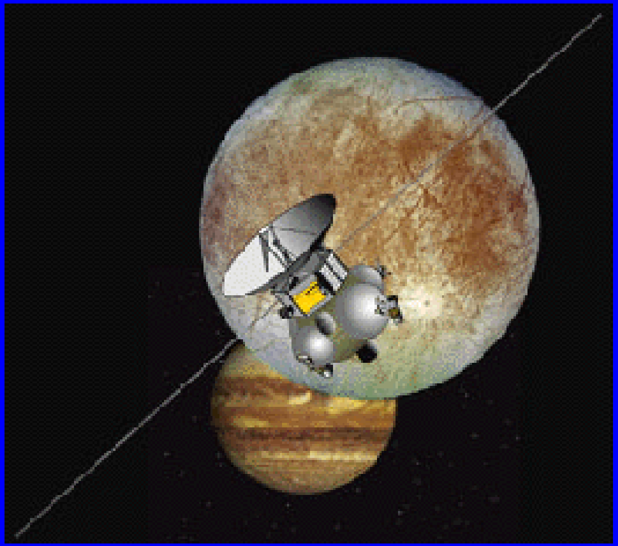
- *Large Class (>$650M)*

1. Europa Geophysical Explorer (EGE)

Europa Geophysical Explorer (EGE)

GOALS:

- Compare Europa, Ganymede, Callisto
- Use tidal effects to characterize the properties of the ice shell and describe the 3D distribution of subsurface ocean
- Elucidate the formation of surface features and seek sites of current or recent activity.
- Identify and map surface compositional materials with emphasis on compounds of astrobiological interest.
- Prepare for a future lander mission.



Kuiper Belt / Pluto (KBP)

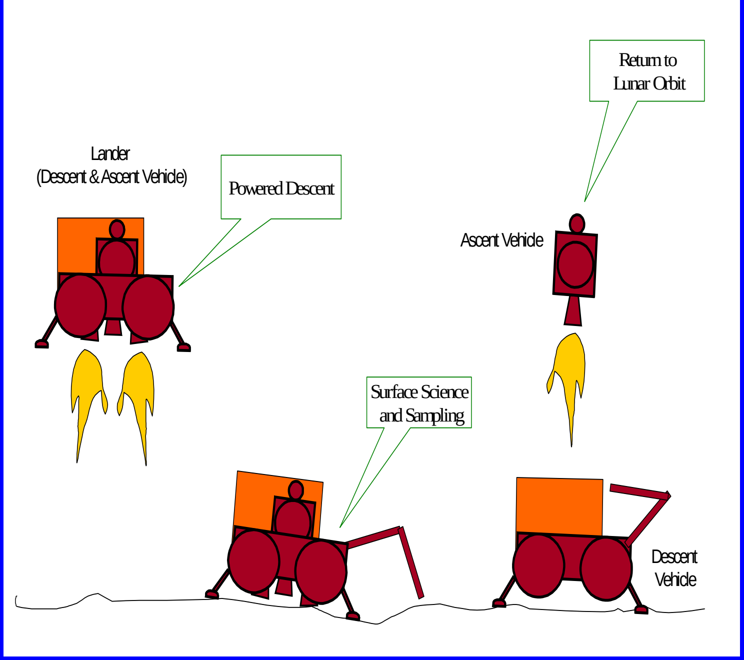
GOALS:

- **Investigate the diversity of the physical and compositional properties of Kuiper belt objects**
- **Perform a detailed reconnaissance of the Pluto-Charon system**
- **Assess the impact history of large (Pluto) and small KBOs**

South Pole Aitken Basin Sample Return (SPA-SR)

GOALS:

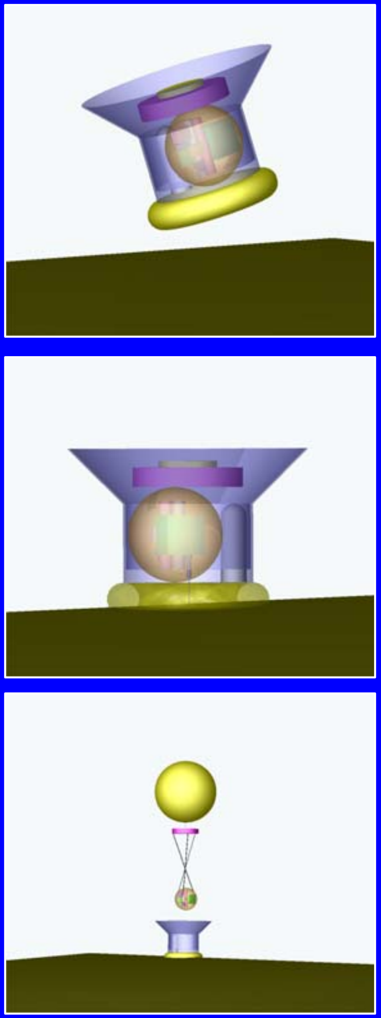
- Obtain samples to constrain the early impact history of the inner solar system
- Assess the nature of the Moon’s interior and the style of the differentiation process
- Develop robotic sample acquisition, handling, and return technologies



Venus In-situ Explorer (VISE)

GOALS:

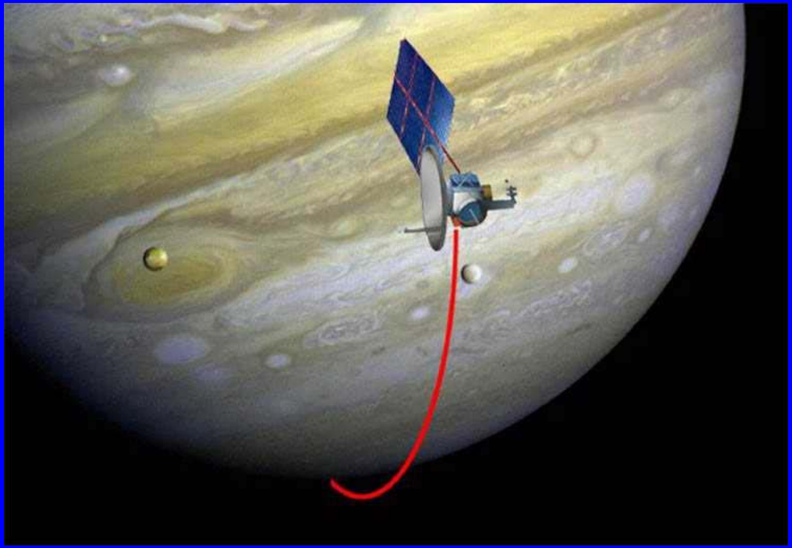
- **Determine the compositional and isotopic properties of the surface and atmosphere**
- **Investigate the processes involved in surface-atmosphere interactions**
- **Elucidate the history and stability of Venus's atmospheric greenhouse**



Jupiter Polar Orbiter with Probes (JPOP)

GOALS:

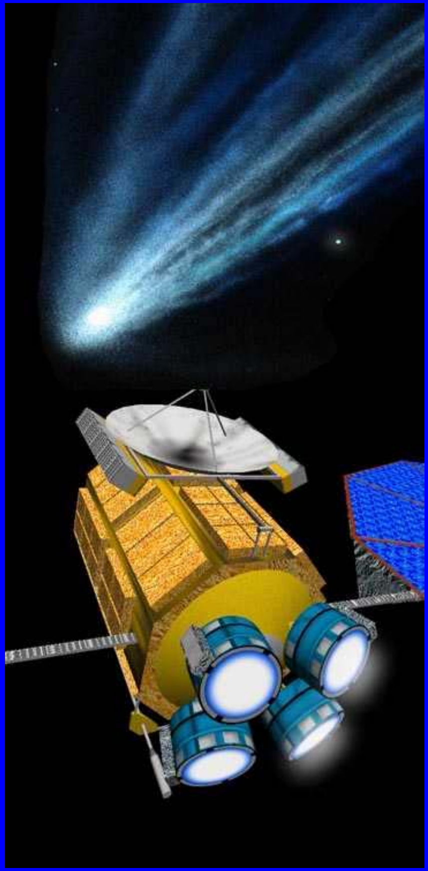
- Determine if Jupiter has a central core to constrain ideas of its formation
- Ascertain the planetary water abundance
- Learn if the winds persist into Jupiter's interior or are confined to the weather layer
- Assess the structure of Jupiter's magnetic field to learn how the internal dynamo works
- Measure the polar magnetosphere to understand its rotation and relation to the aurora



Comet Surface Sample Return (CSSR)

GOALS:

- Return near-surface cometary materials to Earth for detailed compositional, isotopic, and structural analysis
- Assess the detailed organic composition of the cometary nucleus
- Assess the porosity and other physical properties of nuclear material
- Assess the physical relationship among volatiles, ices, organics and refractories and their relationship to porosity
- Assess the isotopic and mineralogic content at both microscopic and macroscopic scales assess the detailed organic composition of the cometary nucleus



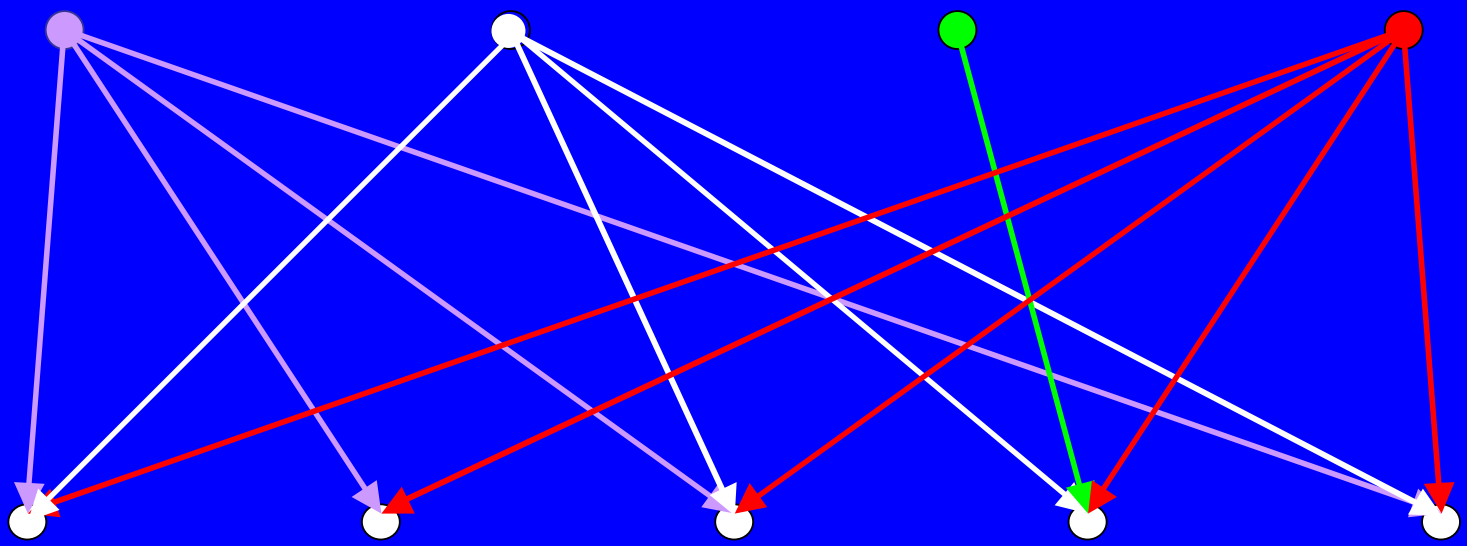
SURVEY THEMES

The First Billion Years of Solar System History

Volatiles and Organics: The Stuff of Life

The Origin & Evolution of Habitable Worlds

Processes: How Planets Work



1) Kuiper Belt-Pluto Explorer

2) Lunar South Pole-Aitken Basin Sample Return

3) Jupiter Polar Orbiter with Probes

4) Venus In-Situ Explorer

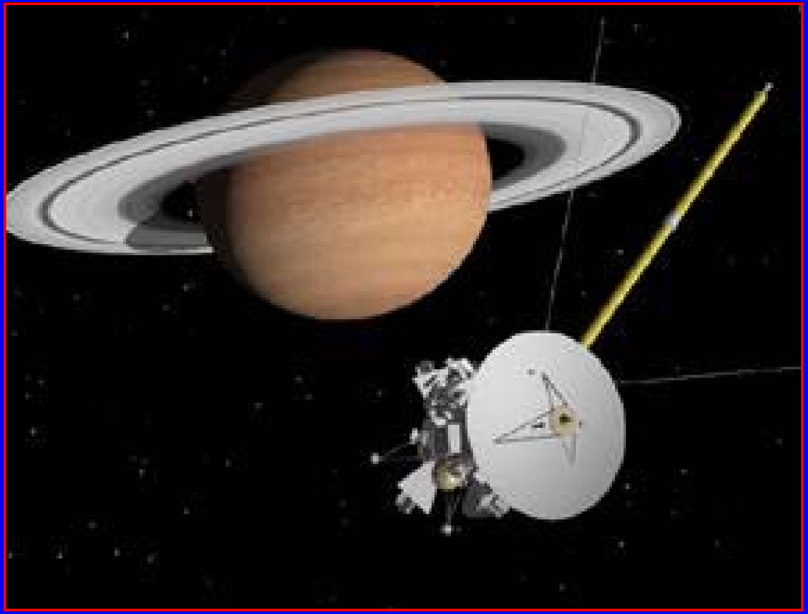
5) Comet Surface Sample Return

Increasing Technical Challenge

Extended Missions: Example of Cassini

GOALS:

- Follow up on significant discoveries during the nominal mission
- Extend spatial coverage on Titan through changing orbital geometry
- Lengthen time coverage of dynamical phenomena at Saturn and Titan



Primary Recommendations on Solar System Exploration Infrastructure (1):

- We recommend that NASA commit to significant new investment in **advanced technology** in order that future high-priority flight missions can succeed..

•Power: Advanced RTGs
•Power: In–space Nuclear power source
•Propulsion: Nuclear--powered electric propulsion
•Propulsion: Advanced electric engines
•Propulsion: Aerocapture
•Communications: Ka band
•Communications: Optical
•Architecture: Autonomy
•Avionics: Advanced packaging and miniaturization
•Instrumentation: Miniaturization
•Entry to landing: Autonomous entry, precision landing
•In-situ ops: Sample gathering, handling and analysis
•In-situ ops: Instrumentation
•Mobility: Autonomy
•Contamination: Forward-contamination avoidance
•Earth return: Ascent vehicles

Mission Priorities: Mars Flight Missions (beyond 2005):

- ***Small Class (<$325M)***
  - **Mars Scout Line**
  - **Mars Upper Atmosphere Orbiter (MAO)**
- ***Medium Class (<$650M)***
  - **Mars Smart Lander (MSL)**
  - **Mars Long-lived Lander Network (MLN)**
- ***Large Class (>$650M)***
  - **Mars Sample Return preparation so that *its implementation can occur early in the decade 2013-2023* (MSR)**

Mars Smart Lander (MSL)

GOALS:

- Mineralogy,chemistry, and geology of a water-modified environment
- Establish ground-truth for orbital observations
- Measurement of atmospheric properties
- Test for the presence of organics
- Test and validate technology required for sample return

Mars Long-lived Lander Network (MLN)

GOALS:

- Long-term (1 martian year) measurements from a network of stations (4 minimum)
- Determine the interior structure and activity
- Measure the properties of the ground-level atmosphere for analysis of meteorology, atmospheric origin and evolution, chemical stability, and atmospheric dynamics

Mars Upper Atmosphere Orbiter (MAO)

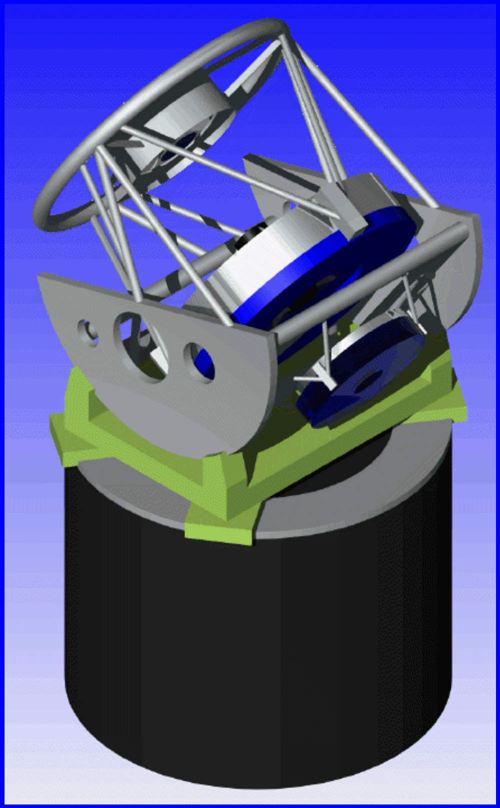
GOALS:

- Determine the dynamics of the middle and upper atmosphere
- Ascertain the rate of atmospheric escape
- Measure the current neutral gas and ion abundances and escape fluxes

Large-aperture Synoptic Survey Telescope (LSST)

GOALS:

- To optically survey the entire available sky to m = 24 magnitudes every week or faster to:
  - Catalog and determine orbits for the population of Near Earth Objects down to 300-m diameter so as to assess the impact threat posed to Earth.
  - Determine the distribution of trans-Neptunian objects and other bodies in the outer solar system (Centaurs, Trojans, long-period comets)
- Joint venture with NSF (A&A DS)



Programmatic Requirements

• Continue vital ongoing programs
• Adjust R&A programs to be consistent with the new program
• Establish *New Frontiers*– competitively selected missions capped at $650M
• Fly flagship missions once per decade
•Support organizations providing vital services (e.g. mission design, navigation, etc)
• Facilitate international ventures.

Primary Recommendations on Solar System Exploration Infrastructure (2):

- Increase **R & A programs** to a level that parallels the growing number of missions, amount of data, and diversity of objects studied (about 25% of the overall flight budget).

- NASA should establish a broad and vigorous **Sample Analysis Program** to support instrument development, laboratory facilities, and the training of researchers well before sample return occurs.

- Integrate **Astrobiology** objectives with those of the other disciplines

Aspects of Competitive Selection of New Frontiers Missions that need further consideration:

- Competition will lead to secrecy in the conceptual phase of a mission

- Competition may lead to a substantial increase in the overall costs of the pre-selection stage

- Competition may lead to conflict of interest at NASA centers

Solar System Exploration Survey:

- Provides a logical and compelling basis for flight mission selection based on profound motivational questions, clear scientific goals, and key scientific questions.
- Ensures a vigorous flight program that will significantly address all of the key scientific questions identified for the coming decade
- Requires a vital, productive, and creative infrastructure to support the flight program
- Encourages essential technological developments

Backup viewgraphs

Relationship Between Scientific goals and Scientific Themes:

Determine how life developed in the solar system, where it may have existed, whether extant life forms exist….

Learn how the Sun's retinue of planets originated and evolved.

Discover how the basic laws of physics and chemistry, acting over aeons, lead to diverse phenomena…

Understand how physical and chemical processes determine the main characteristics of the planets…

- **The first billion years of solar system history**
- **Volatiles and organics: The stuff of life**
- **The origin and evolution of habitable worlds**
- **Processes: How planetary systems work**

Explore the terrestrial space environment to discover what potential hazards…

- **The origin and evolution of habitable worlds**

Scientific Goals for Solar System Exploration:

- **Determine how life developed in the solar system, where it may** have existed, whether extant life forms exist beyond Earth, and in what ways life modifies planetary environments;
- **Understand how physical and chemical processes determine the** main characteristics of the planets, and their environments, thereby illuminating the workings of the Earth;
- **Learn how the Sun’s retinue of planets originated and evolved;**
- **Explore the terrestrial space environment to discover what** potential hazards to the Earth's biosphere may exist;
- **Discover how the basic laws of physics and chemistry, acting** over aeons, can lead to the diverse phenomena observed in complex systems, such as planets.

Priorities for New Ground-Based Activities:

Enter an equal partnership with NSF to build and operate a

- **Large-aperture Synoptic Survey Telescope (LSST)**

Summary of Flight Mission Prioritization:

- 27 missions identified in broad survey
- 16 missions placed on short list
- 13 missions included in priority listings
- Of the 5 New Frontiers missions, 3 are prime and 2 are included to account for uncertainties, encourage further growth, and to indicate possible future directions

Missions: Key Scientific Questions:

Kuiper Belt / Pluto (KBP)

A flyby mission of several Kuiper Belt objects, including Pluto/Charon, to discover their physical nature and determine the collisional history of the Kuiper Belt.

- **What processes marked the initial stages of planet formation?**
- **How did the impactor flux decay during the solar system's youth, and in what ways(s) did this decline influence the timing of life's emergence on Earth?**
- **How do the processes that shape the contemporary character of planetary bodies operate and interact?**
- **What does our solar system tell us about the development and evolution of extrasolar planetary systems, and vice versa?**

Missions: Key Scientific Questions:

South Pole Aitken Basin Sample Return (SPA-SR)

A mission to return samples from the solar system's deepest impact crater, which exposes the interior of a differentiated body.

- **What is the character of the lower crust and upper mantle?**
- **How did the impactor flux decay during the solar system's first 500 million years, and in what way(s) did this decline influence life's emergence?**
- **How did early processes that shaped the contemporary character of planetary bodies operate and interact?**

Missions: Key Scientific Questions:

Jupiter Polar Orbiter with Probes (JPOP)

A close-orbiting polar spacecraft equipped with various instruments and a relay for three probes that make measurements below the 100+bar level.

- **Over what period did the gas giants form, and how did the birth of the ice giants (Uranus, Neptune) differ from that of Jupiter and its gas-giant sibling, Saturn?**
- **What is the history of volatile compounds, especially water, across our solar system?**
- **How do the processes that shape the contemporary character of planetary bodies operate and interact?**
- **What does our solar system tell us about the development and evolution of extrasolar planetary systems, and *vice versa?***

Missions: Key Scientific Questions:

Venus In-situ Explorer (VISE)

A core sample of Venus will be lifted into the atmosphere for compositional analysis; simultaneous atmospheric measurements.

- **What global mechanisms affect the evolution of volatiles on planetary bodies?**
- **Why have the terrestrial planets differed so dramatically in their evolutions?**
- **How do the processes that shape the contemporary character of planetary bodies operate and interact?**

Missions: Key Scientific Questions:

Comet Surface Sample Return (CSSR)

Several pieces of a comet's surface will be returned to Earth for elemental, isotopic, molecular, mineralogical, and structural analysis.

- **What processes marked the initial stages of planet formation?**
- **What is the history of volatile compounds, especially water, across our solar system?**
- **What is the nature of organic material in our solar system and how has this matter evolved?**
- **How do the processes that shape the contemporary character of planetary bodies operate and interact?**

Missions: Key Scientific Questions:

Europa Geophysical Explorer (EGE)

An orbiter of Jupiter's ice-encrusted satellite will seek the nature and depth of its ice shell and ocean.

- **What planetary processes are responsible for generating and sustaining habitable worlds, and where are the habitable zones in our Solar System?**
- **How do the processes that shape the contemporary character of planetary bodies operate and interact?**

Missions: Key Scientific Questions:

Mars Upper Atmosphere Orbiter (MAO)

A spacecraft dedicated to studies of Mars's upper atmosphere and plasma environment.

- **What global mechanisms affect the evolution of volatiles on planetary bodies?**
- **How do the processes that shape the contemporary character of planetary bodies operate and interact?**

Missions: Key Scientific Questions:

Mars Smart Lander (MSL)

A lander to carry out sophisticated surface observations and to validate sample return technologies.

- **What planetary processes are responsible for generating and sustaining habitable worlds, and where are the habitable zones in our Solar System?**
- **Why have the terrestrial planets differed so dramatically in their evolutions?**
- **How do the processes that shape the contemporary character of planetary bodies operate and interact?**

Missions: Key Scientific Questions:

Mars Long-lived Lander Network (MLN)

A globally distributed suite of landers equipped to make comprehensive measurements of the planet's interior, surface and atmosphere.

- **Why have the terrestrial planets differed so dramatically in their evolutions?**
- **How do the processes that shape the contemporary character of planetary bodies operate and interact?**

Missions: Key Scientific Questions:

Mars Sample Return (MSR)

A program to return several samples of the Red Planet to search for life, develop chronology and define ground-truth.

- What planetary processes are responsible for generating and sustaining habitable worlds, and where are the habitable zones in our Solar System?
- Does (or did) life exist beyond the Earth?
- Why have the terrestrial planets differed so dramatically in their evolutions?
- How do the processes that shape the contemporary character of planetary bodies operate and interact?

Mars Sample Return (MSR)

GOALS:

– Return samples to Earth from a site selected on the basis of remotely sensed and in situ data that will address key scientific questions

– Precisely measure the geochemical, mineralogical, and volatile content of samples in Earth laboratories

– Assess the biological potential of Mars

– Provide the ultimate ground truth for orbital and in situ data to guide future exploration

Missions: Key Scientific Questions:

Cassini Extended Mission (CASx)

Extension of orbiter mission at Saturn

- What is the nature of organic material in our solar system and how has this matter evolved?
- How do the processes that shape the contemporary character of planetary bodies operate and interact?
- What does our solar system tell us about the development and evolution of extrasolar planetary systems, and *vice versa*?

Ground Based Facilities: Key Scientific Questions:

Large-aperture Synoptic Survey Telescope (LSST)

A facility to survey objects in the Kuiper Belt and comets and asteroids in near-Earth orbits.

- **What hazards do solar system objects present to Earth's biosphere?**
- **What does our solar system tell us about the development and evolution of extrasolar planetary systems, and vice versa?**

Recommendations on Mission Lines:

- We recommend continuance of the **Discovery** mission flight rate at the current level of one launch every 18 months…
- We strongly endorse the President's initiative on **New Frontiers** with competitively selected, medium-class missions with flights every 2 – 3 years…
- We recommend that **Flagship,** large class, missions be developed and flown at a rate of about one per decade…
- For many missions, particularly those of the **large class**, we recommend that NASA encourage and continue to pursue cooperative programs with other nations…
- For **large missions**, a broad cross-section of the community should be involved in the early planning stages…
- We recommend that early planning be done to provide adequate funding of **mission extensions,** particularly flagship missions and missions with international partners…

Recommendations on the Mars Program:

- We endorse the current science-driven strategy of ***seeking, in situ measurements, and sampling*** to understand Mars as a planet and to understand its astrobiological significance…

- We recommend that NASA begin its planning for **Mars Sample Return (MSR)** missions so that their implementation can occur early in the decade 2013-2023…

- We support the initiation of a series of small-class **Mars Scout** missions for flights at alternating Mars launch opportunities in a program modeled on the Discovery program.

Plan and Status

- Planned completion date – May-June, 2002; Actual: July 4. 2002
- Plan:
  - **Five phases:** 1) Information gathering – especially direct community input, 2) Formulation of positions, 3) Writing, 4) Review, 5) Production
  - **Overlap phases** as much as possible, focus on production of written report strawman drafts and definition of report structure from the start…
  - **Divide responsibilities** for addressing the charge between panels and SC
    - Big-picture of SSE – *steering committee*
    - Broad survey of current state of knowledge – *panels*
    - Identification of key questions – *panels - then steering committee*
    - Prioritized list of missions and facilities – *panels - then steering committee*
  - **Stimulate broad community input**
    - Town hall and open meetings as early as possible
    - Early stimulation of ad hoc community reports (DPS committee has been very proactive and successful in generating inputs to the Survey)
  - **Coordinate with other groups that have overlapping interests**
    - SPDS, AADS, COEL, SSES…

Plan and Schedule

Steering committee schedule:

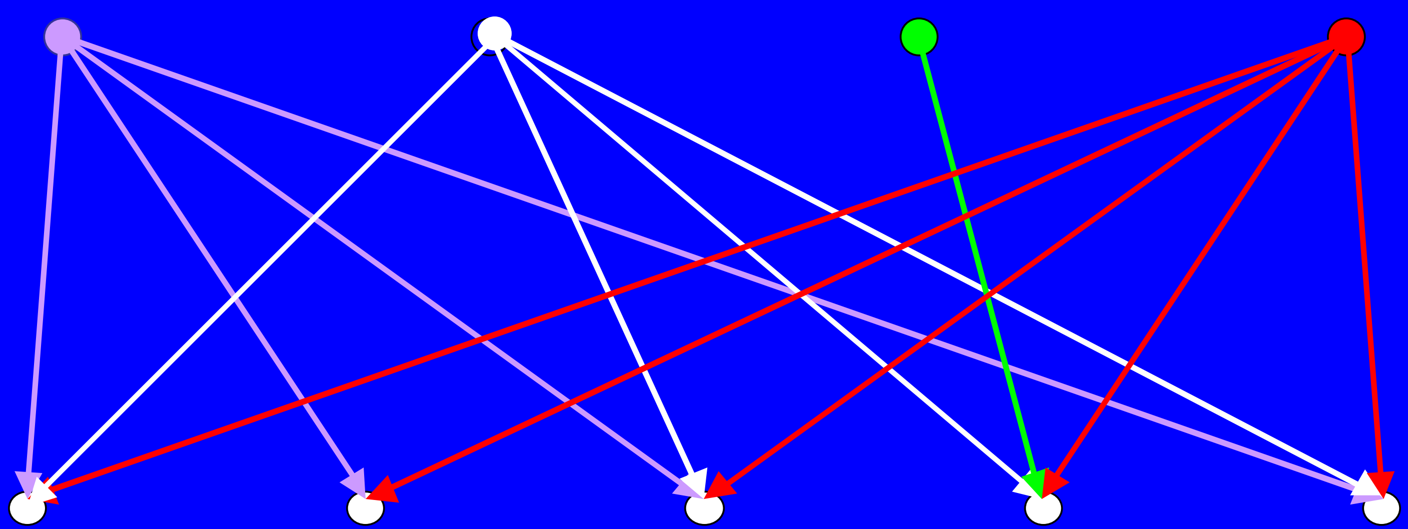
- 1 - Washington, D.C. July 18-20, 2001 (2.5 d)
  - Survey organization, information gathering
- 2 - Washington, D.C. Sept 19-20 – cancelled
- 3 - Irvine, CA. Nov 14-16, 2001 (2.5d)
  - Information gathering
- 4 - Tucson, AZ, Feb 26-Mar 1, 2002 (3.5d)
  - Survey positions; report writing
- 5 - Washington, D.C. Mar 26-28, 2002
  - Survey positions finalized. First draft writing completed.

NRC Review process – Apr 10 through July 4

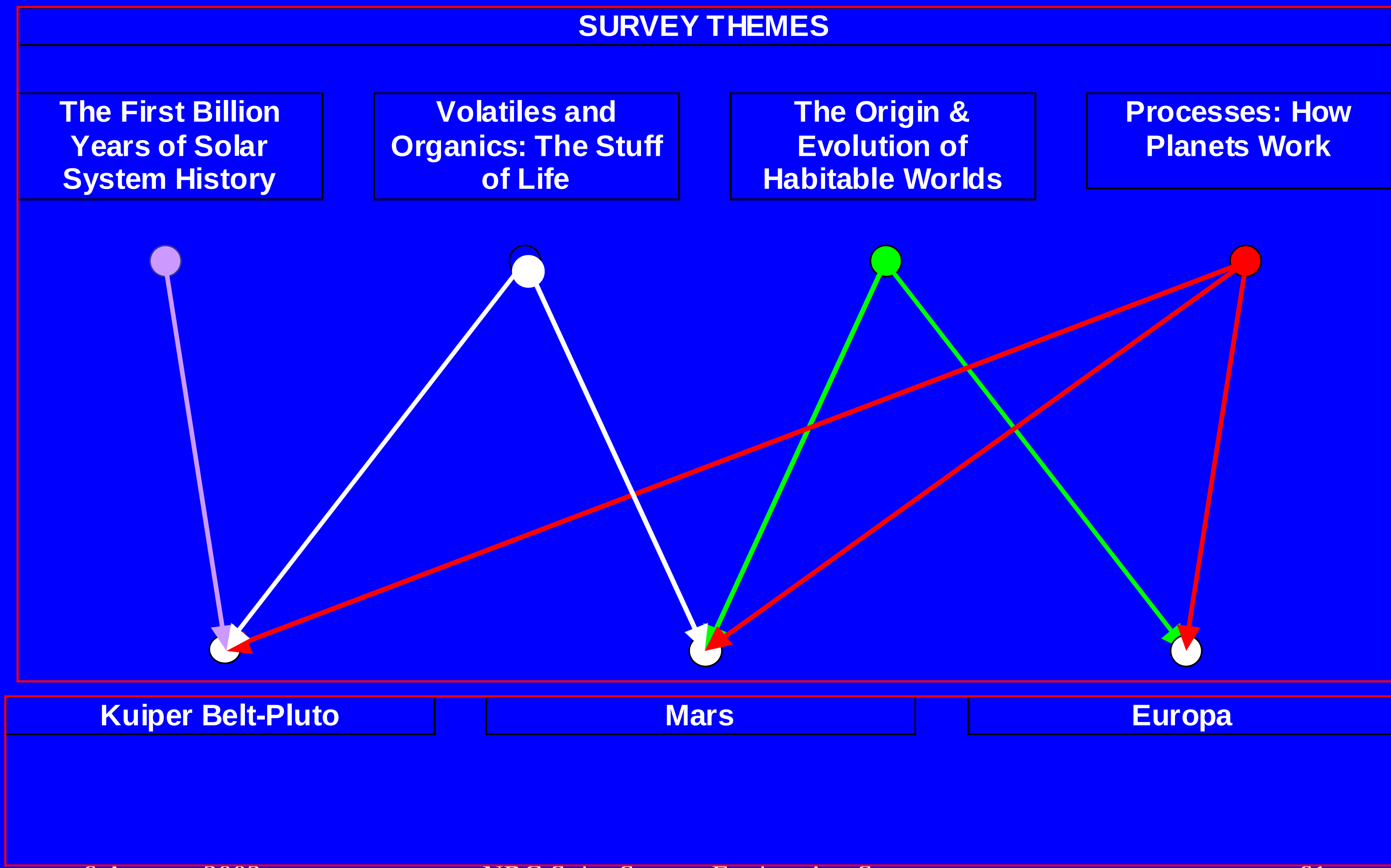
First NASA briefing – July 9, 2002

SURVEY THEMES

The First Billion Years of Solar System History	Volatiles and Organics: The Stuff of Life	The Origin & Evolution of Habitable Worlds	Processes: How Planets Work



Kuiper Belt-Pluto Explorer	Lunar South Pole-Aitken Basin Sample Return	Jupiter Polar Orbiter with Probes	Venus In-Situ Explorer	Comet Surface Sample Return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Kuiper Belt-Pluto
Mars
Europa

Recent Significant Discoveries in Solar System Exploration:

- Discovery of extrasolar planetary systems
- Discovery of the Kuiper Belt
- Possible subsurface oceans within the icy Galilean satellites
- Evidence that Mars might have been hospitable to life in the past
- Disputed evidence for life on ancient Mars
- Identification of Chixulub crater and observations of giant impacts of comet fragments on Jupiter

Themes used by the panels…

- **Primitive Bodies:** Building Blocks and the Origins of Organic Matter in the Solar System.
- **The Inner Planets:** Key to Habitable Worlds
- **Mars:** The Evolution of an Earth-like Planet
- **Giant Planets:** Keys to Solar System Formation
- **Large Satellites:** Active Worlds and Extreme Environments

PANEL THEMES

Inner Planets
- The Past: Where Did We Come From?
- The Present: What's Going On?
- The Future: Where Are We Going?

Mars
- Planetary Structure & Evolution
- What is the Potential of Mars as an Abode of Life?
- Water, Atmosphere, and Climate

Giant Planets
- Origin & Evolution of the Giant Planets
- Interiors & Atmospheres
- Rings & Plasmas

Large Satellites
- Origin & Evolution of Satellite Systems
- Origin & Evolution of Water-Rich Environments in the Icy Satellites
- Exploring Organic-Rich Environments
- Understanding Dynamic Planetary Processes

Primitive Bodies
- Primitive Bodies as the Building Blocks of Planets
- The Origins of Organic Matter That Led to Life

INTEGRATED BY STEERING GROUP

The First Billion Years of Solar System History
- What caused the planets to form?
- How are gas giants different from ice giants?
- How quickly did the impactor flux decrease, and what did this mean for life?

Volatiles and Organics: The Stuff of Life
- What is the history of volatile materials, especially water, in our solar system?
- What is the history of organic material in our solar system?
- How does planetary evolution affect volatiles?

The Origin & Evolution of Habitable Worlds
- Where are habitable zones, and how are they formed?
- Does (or did) life exist beyond the Earth?
- Why did the terrestrial planets diverge evolutionally?
- What hazards do solar system objects present to Earth's biosphere?

Processes: How Planets Work
- How to current planetary processes interact?
- What does our solar system tell us about other solar systems, and vice versa?

Mission Priority by Panel

Panel	Mission Concept Name	Cost Class
Inner Planets		
	Venus In-Situ Explorer	Medium
	South Pole-Aitken Basin Sample Return	Medium
	Terrestrial Planet Geophysical Network	Medium
	Venus Sample Return	Large
	Mercury Sample Return	Large
	Discovery Missions	Small
Primitive Bodies		
	Kuiper Belt-Pluto Explorer	Medium
	Comet Surface Sample Return	Medium
	Trojan/Centaur Reconaissance Flyby	Medium
	Asteroid Rover/Sample Return	Medium
	Comet Cryogenic Sample Return	Large
	Discovery Missions	Small
Giant Planets		
	Cassini Extended Mission	Small
	Jupiter Polar Orbiter with Probes	Medium
	Neptune Orbiter with Probes	Large
	Saturn Ring Observer	Large
	Uranus Orbiter with Probes	Large
	Discovery Missions	Small
Large Satellites		
	Europa Geophysical Explorer	Large
	Europa Lander	Large
	Titan Explorer	Large
	Neptune Orbiter/Triton Explorer	Large
	Io Observer	Medium
	Ganymede Orbiter	Medium
	Discovery Missions	Small
Mars		
	Mars Sample Return	Large
	Mars Smart Lander	Medium
	Mars Long-Lived Lander Network	Medium
	Mars Upper Atmosphere Orbiter	Small
	Mars Scouts	Small

- Missions listed in Priority Order
- Missions in bold face were selected by the Steering Group for overall prioritization